

Systematics of quarkonium production ^{*}

G. A. Schuler[†] and R. Vogt

Some time ago we [1] showed that existing quarkonium production data at fixed-target energies are, in fact, compatible with the assumption that the non-perturbative transition of the $Q\bar{Q}$ pair to quarkonium is more universal than expected from the velocity-scaling rules. Low-energy data are well reproduced if this infinite sum is truncated to a single term

$$\sigma \left[H \left(nJ^{PC} \right) \right] = F[nJ^{PC}] \tilde{\sigma} \left[Q\bar{Q} \right] . \quad (1)$$

We demonstrate that the colour-evaporation model (CEM) of eq. (1) also accounts for quarkonium production at the Tevatron. The number of non-perturbative parameters is minimal, giving the model great predictive power.

The short-distance part of eq. (1) is the perturbative subthreshold cross section expanded in powers of $\alpha_s(\mu)$ where $\mu \propto m_Q$. Specifying to charm, the cross section is

$$\tilde{\sigma} [c\bar{c}] = \int_{2m_c}^{2m_D} dM_{c\bar{c}} \frac{d\sigma [c\bar{c}]}{M_{c\bar{c}}} \quad (2)$$

where $\sigma[c\bar{c}]$ is the *spin- and colour-averaged* open heavy-quark pair production cross section. The CEM is hence based on two ingredients. First, the quarkonium dynamics are assumed to be identical to those of low mass open $Q\bar{Q}$ pairs. All perturbative QCD corrections apply to the short-distance cross section and hence are identical for open and bound heavy-quark production. Second, although the $Q\bar{Q}$ pair is produced at short distances in different states, distinguished by colour, angular momentum, relative momentum, and their relative production rates may be different for different high-energy collisions, the average over many long-distance matrix elements, combined in the long-distance factor $F[nJ^{PC}]$, determines the probability to form a specific bound state. Necessarily, the factor F needs to be universal, *i.e.* process- and kinematics-independent.

The long-distance factors determined from the low-energy total cross sections are

$$F_{tot}[J/\psi] = 2.5\% \quad (3)$$

$$\sum_{n=1}^3 B[\Upsilon(nS) \rightarrow \mu\mu] F_{tot}[\Upsilon(nS)] = 1.6 \times 10^{-3} .$$

Here the subthreshold cross sections were calculated in next-to-leading order (NLO) using the MRS D-' parametrization [2] of the parton-distribution functions (PDF) with renormalization and factorization scales μ_R and μ_F chosen to be $\mu_R = \mu_F = 2m_c = 2.4 \text{ GeV}$ and $\mu_R = \mu_F = m_b = 4.75 \text{ GeV}$, respectively. The results in eq. (4) are rather insensitive to variations of the parameters in the open heavy-quark cross section, if they are tuned to the open heavy-flavour total cross section data.

The transverse momentum distributions of prompt charmonium production (*i.e.* not originating from B decays) and bottomonium production at the Tevatron energy $\sqrt{s} = 1.8 \text{ TeV}$, with normalizations extracted from eq. (4), are in good agreement with the data, typically better than 50%. The CEM prediction is based on the subthreshold cross section calculated to $O(\alpha_s^3)$, NLO for the p_T integrated cross section but LO only for the p_T distribution. In the absence of the NLO corrections to the p_T spectrum one might apply a K factor to account for the unknown higher-order corrections.

[1] P.L. McGaughey *et al.*, Int. J. Mod. Phys. **A10** (1995) 2999.

[2] A.D. Martin, R.G. Roberts and W.J. Stirling, Phys. Lett. **B306** (1993) 145.

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[†]Theory Division, CERN